Progress Report

ALICE-USA Collaboration

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Contents:

May 2003

A. Progress in the last 12 Months

A.I. Introduction

There has been an intensive ALICE-USA simulation effort during the last year in support of the claimed physics capabilities and optimization of the design parameters of the large electromagnetic calorimeter proposed by the ALICE-USA collaboration for the ALICE experiment at the LHC. Several one-week simulation meetings have been held in conjunction with weekly progress meetings via conference calls. There has been significant support at all levels on the EMCal effort from the ALICE collaboration. The total integrated ALICE-USA simulation effort now corresponds to about 10 man-years, which can be only briefly summarized in this report.

The simulations reported here have been preformed fully within the official ALICE ALI-ROOT simulation framework with a complete description of the proposed EMCal. While the response of the EMCal has been fully simulated, including all material and detectors in the ALICE geometry, the response of the tracking system has been parameterized according to parameters developed from full simulation studies performed by ALICE. Given the TPC's 98% tracking efficiency this "fast tracking" is not a significant limitation. The EMCal specific simulation data production and analysis used for the results presented here has been preformed at NERSC at LBNL. The level of ALICE-USA computing effort has been comparable to that used for all analyses in the official ALICE mock data challenge, which occurred during this same time period at CERN.

The main thrust of the recent ALICE-USA simulation effort has been to address the major concerns raised at the first DOE review. Namely,

1) the adequacy of the limited EMCal acceptance to address the high P_T physics of interest, and the related capabilities for correlation measurements (jet+jet, γ+jet, etc) and jet flavor tagging,
2) the trigger capabilities and potential trigger biases,
3) the need for the soft physics capabilities of ALICE for the proposed hard physics program, and
4) the γ/π^0 discrimination capabilities of the EMCal relative to the existing PHOS electromagnetic calorimeter of ALICE, and relevance to the γ+jet measurements.

In addition to the above, simulations were performed with different EMCal configurations to optimize the EMCal design. Three different transverse segmentations were investigated as well as configurations with a preshower section, or a coarsely segmented hadronic section. The simulations indicated little benefit to the jet performance or photon identification (items 1 and 4) from the preshower or hadronic sections. As a result, the preshower section of the EMCal, included in the initial proposal, has been eliminated. On the other hand, the photon vs hadron identification improves continuously as the EMCal segmentation approaches the Moliere radius of the calorimeter. For this reason the transverse segmentation of the calorimeter has been increased from that proposed initially.

In brief summary, the simulations have confirmed that the excellent capabilities of ALICE necessary to perform the measurements of the soft physics program enable detailed, high resolution analyses of jets down to rather low jet energies (item 3). It is generally agreed that the most interesting region for the jet quenching studies is the lowest jet energy region. The detailed simulations confirm that in order to optimally investigate low P_T jets in central PbPb collisions, the jet-cone window must be restricted to a region much smaller than the acceptance of the proposed EMCal. This fact, together with the large rate for low P_T jets, demonstrates that the proposed EMCal acceptance is perfectly adequate for the proposed studies (item 1). Simulation studies have also demonstrated that a simple EMCal cluster trigger provides an effective jet trigger with negligible bias for the jet fragmentation studies (item 2).

In addition, the ALICE capabilities to use other hard probes explicitly investigated with the recent simulations have been:

Open Charm	Upsilon family suppression (down to $P_T \sim 0$)	Direct Photons
Open Beauty	J/Ψ family suppression (down to $P_T \sim 0$)	Inclusive electrons and hadrons
Inclusive Jets	Tagged Jets (γ, W,Z and s,c,b flavor tagging)	Di-Jets

In the following, these topics are largely omitted as we focus mainly on the jet quenching and fragmentation function measurement, i.e., P_T spectra, of particles in jets, issues raised in the previous review.

Finally, we do wish to emphasize again that ALICE-USA is a significant collaboration with interests that span all of relativistic heavy ion physics and with recognized world leadership in fields as diverse as strangeness physics, collective flow, HBT, E-by-E, thermal and direct photons, high P_T and many more. We fully believe that the new and unexpected phenomena seen at RHIC in areas such as HBT, elliptic flow, meson to baryon ratios, suppression at intermediate P_T, and so forth, must be explored in the new regime of temperature and density that opens at the LHC, and into the high Q^2 domain well beyond the reach of RHIC. It is vitally important that the US community, who pioneered this field, continue to participate with a leading role in the full breadth of measurements in what is certain to be an exciting period of discovery. As in our first proposal we do not discuss the full menu of physics interests of the ALICE-USA Collaboration and the particular suitability of the ALICE experiment to each of these. Rather, we focus only on the particular capabilities of the proposed EMCal with respect to hard probes of the QGP. We explicitly illustrate the capability that the ALICE experiment has to track these observables down to the lowest possible P_T. Our interest is to complete a study that spans the lowest accessible P_T to the highest P_T of interest as a probe of the medium[1]. We emphasize that it is generally believed that the most interesting physics related to hard parton production and propagation is to be seen in the low to intermediate P_T range, where medium effects are strongest.

A.II. Leading Particles and Inclusive Jets in PbPb Collisions at Low P_T

We begin our discussion of jet physics in ALICE in the low P_T end of the spectrum in PbPb collisions. In this P_T range, ~5 – 30 GeV/c, where the jet cross sections at RHIC energy are large, we have the greatest overlap with ongoing and future measurements in STAR and PHENIX. In this P_T range, however, the complexity of central heavy ion collision, limits the experimental options since jets, even at the LHC, cannot be individually reconstructed as distinct objects. Here in ALICE as presently in STAR and PHENIX, we are limited to discern the physics of jet quenching from intermediate to high P_T inclusive spectra and spatial and energy correlation studies both event-by-event and inclusively. Clearly these restrictions limit what can be unambiguously learned about jet quenching (for example no primary parton P_T can be deduced) but they provide the greatest opportunity to complement and extend RHIC measurements to the higher temperature and denser QGP produced at LHC energies.

The physics issues in this low P_T regime may be distinctly different from the high P_T regime which is uniquely accessible at the LHC. For example, at lower P_T and at RHIC, fast partons my undergo fragmentation while still inside the dense medium. This possibility is certainly suggested by the "disappearance" of away side jets as discussed in STAR. This scenario invalidates the factorization of production and fragmentation used in most QCD analyses of jet quenching. However, at sufficiently high P_T accessible at the LHC, the limit of fragmentation in vacuum is certainly reached. Potentially, therefore, the experimental manifestations of jet quenching may evolve considerably over the P_T range accessible at the LHC**. Indeed, a central theme of our proposed program is to study the evolution from the RHIC regime of low P_T partons in dense media, where jets may be very strongly quenched, to the high P_T regime where vacuum fragmentation of quenched partons dominates.**

The physics of very low P_T jet quenching is unique to the ALICE experiment at the LHC. These measurements require the full "soft physics" power of the TPC[2] and related tracking elements along with the EMCal and the full suite of the ALICE particle identification tools to fully diagnose the correlations discussed in the following (item 3). These measurements are an essential part of our program to fully characterize parton propagation in dense matter over the widest possible energy range.

A.II.1 Inclusive Jets at Very Low P_T

Correlations with leading particles are used to reconstruct very low P_T jets. We apply an algorithm similar to the one used for the CDF charged jet analysis. All particles with a $P_T > P_T^{seed}$ are leading particle candidates $\mathcal{P}_i$ and are ordered according to their P_T. We start with the highest P_T candidate $\mathcal{P}_0$ and record the distances R in the $\eta - \phi$ plane between $\mathcal{P}_0$ and all other particles. If another $\mathcal{P}_i$ is found within a distance $R < R_{sep}$ it is eliminated from the list of candidates. The procedure continues with the next candidates until no candidate is left.

To see same-side angular correlations intrinsic to HIJING events, we plot the particle density $(2\pi R)^{-1}$ dN/dR. Figure 1 shows such distributions for $P_T^{seed} = 5$ GeV/c with a cut on all other particles of $P_T^{all} > 3$ GeV/c. A clear correlation signal from the mini-jets in the HIJING is visible for R < 0.3. The associated P_T spectrum of these ~ 10 – 20 GeV/c jets is shown in the lower panel and is compared to the spectrum of random non-jet background. In real data, this spectrum will reveal the longitudinal redistribution of energy resulting from energy loss for these low energy partons.

[1] There is probably very little physics motivation to consider processes with $P_T > 100 – 150$ GeV/c. Above this range, medium effects are expected to become fractionally insignificant.

[2] The TPC has a track reconstruction efficiency of 98% in its acceptance. Our detailed simulations show that tracking with low efficiency at low P_T or tracking with any significant low P_T cutoff, introduces unacceptable biases and backgrounds in the analysis of very low P_T jets or the low P_T end of fragmentation functions of higher P_T jets..

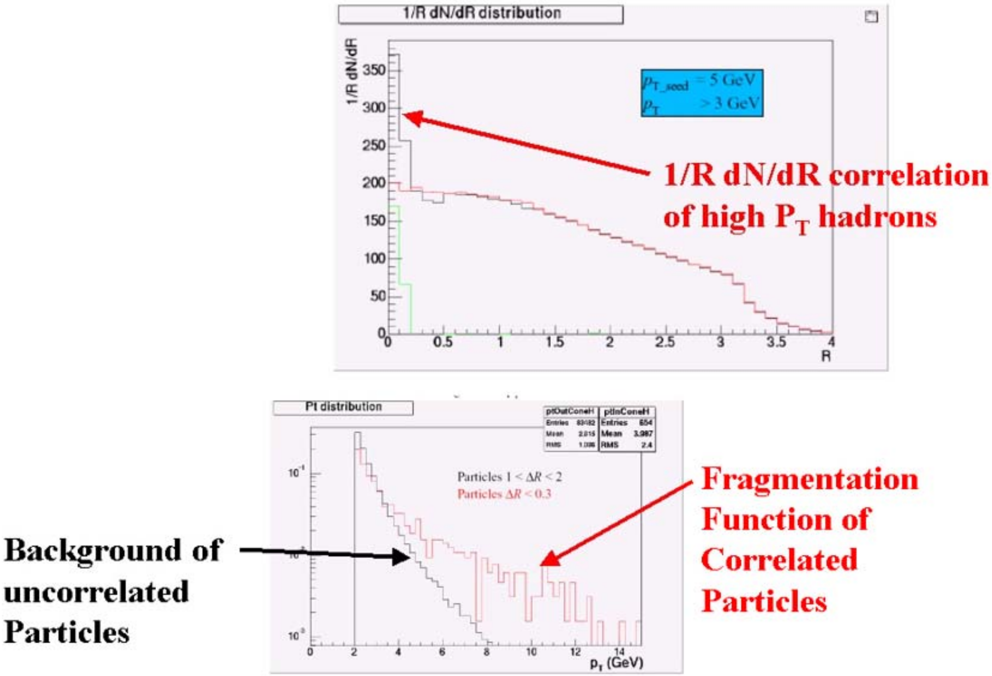


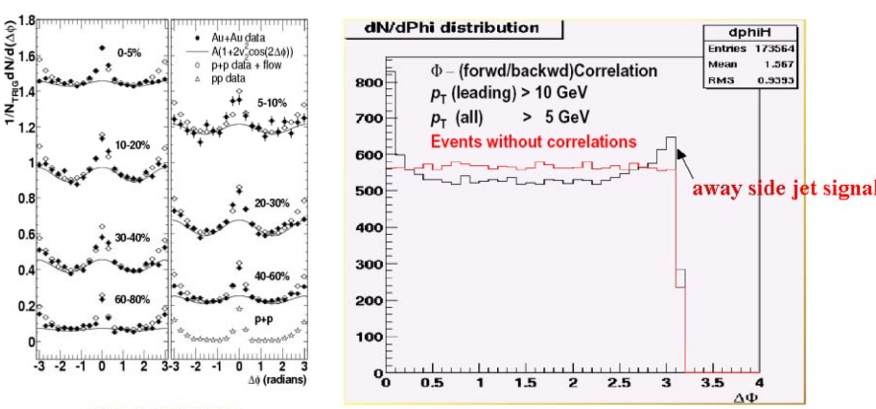
Figure 1. The upper panel shows the same side correlation of minijets produced in HIJING at LHC energy. The uncorrelated background is indicated by the smooth red line. The P_T spectrum of particles in the minijets is shown in the lower panel along with the P_T spectrum of the uncorrelated background. One observable of interest will be the centrality dependence of the P_T spectrum of the correlated particles.

The away side jets associated with low P_T jets seen in figure 1 can be reconstructed through their forward-backward ϕ-correlations. These correlations are more difficult to observe since the possibility of a substantial rapidity gap weakens the η correlation. In figure 2., however, we show the strong $\Delta\phi$ distribution for particles with P_T> 5 GeV/c with respect to leading particles with $P_T^{leading}$ > 10 GeV/c in reconstructed HIJING events. A significant backward peak is observed demonstrating that such an analysis is possible with ALICE at the LHC for these very low P_T jets. This figure also shows the recent STAR results on the ϕ-correlation of high P_T particles as a function of centrality.

In STAR, this analysis was recently shown to imply very strong quenching of the away side jet giving a first quantitative estimates of the energy loss of fast partons in the hot, dense matter. Our simulations show that this class of measurements is not precluded in ALICE at the LHC by the large increase in particle multiplicity or the much wider rapidity plateau. It is important to remember that the "disappearance" of the away side jet seen in STAR, means that the P_T spectrum of away side particles has been shifted below the P_T threshold used to construct the correlation. It will be very important to explore the evolution of this away side quenching as a function of increasing partonic P_T to higher P_T where the extent of quenching will gradually diminish. In ALICE, we will make these measurements beginning at the lowest P_T, comparable to possible measurements at RHIC, upwards to the very highest P_T range of interest (say ~200 GeV/c) where fully reconstructed jets are used (items 1 and 3, above). The ability to track low P_T hadrons with very high efficiency and low background is fundamental to this measurement. Furthermore the excellent particle identification capabilities of ALICE will allow to study correlations between various particle species to investigate the dependence on the jet composition.

ALICE TPC is the perfect tool for this Physics

Figure 2. Simulation of the ϕ-correlation in central HIJING events in ALICE compared to recent STAR results. Although not shown, the P_T spectrum of particles in the away side jet are readily reconstructed to very low P_T in ALICE.



STAR TPC data AuAu

Simulation of ϕ-correlation due to mini jets in central PbPb

A.III Jets at High P_T

A central focus of the ALICE-USA collaboration is to study heavy ion collisions with the use of high P_T, hard parton probes in the range > 50 GeV/c. In combination with the low P_T jet studies from correlation methods discussed above, and γ-jet and Z^0 – jet events discussed in the full proposal, measurements in this high P_T range complete the picture of the parton energy dependence of jet quenching phenomena and open the opportunity for investigating the new range of phenomena associated with heavy quark propagation and flavor tagging. We give only a very brief summary of recent progress.

A.III.1 Jet Rates and Resolutions.

At the LHC, the production rates for jets with P_T >50 GeV/c are many orders of magnitude larger than at RHIC allowing for systematic studies with high statistics in a clean kinematic region, far beyond the limits of the RHIC experiments. Assuming that the 1% probability level of the fragmentation function must be observed with 5% statistics, the inclusive jet rates in ALICE imply a P_T reach to ~ 200 GeV/c with a jet P_T bin size[3] of ~0.1P_T. For constant parton energy loss expected in this energy range, where the asymptotic behavior of the parton dE/dx is reached, the signature of jet quenching, namely suppression of high P_T leading particles, will gradually become fractionally less significant for higher P_T jets. It is expected therefore, that there will be little compelling nuclear physics reason to push beyond jets of 100-150 GeV/c at the LHC. That is to say, the region extending up to ~100 -150 GeV/c is sufficiently wide to allow us to observe the gradual diminution of jet quenching in the very high P_T limit.

In attempting to fully reconstruct jets at the LHC, it is essential to realize that, while the fraction of the jet energy integrated within a given cone radius R approaches 100% asymptotically, the energy of background particles not associated with the jet increases quadratically with R. As a consequence, there exists a cone radius for which the fractional jet resolution is optimum. This is illustrated in figure 3 for jets of P_T = 30, 50, and 100 GeV/c in central PbPb HIJING. The results are obtained with the full simulation of the jet reconstruction in ALICE described below. **A minimum resolution is achieved for cone radii that vary from 0.2 to 0.3 with increasing P_T, with R=0.3 being a reasonable compromise at all energies.** These cone radii corresponds to an effective jet phase space in PbPb collisions which is only 5 -10% of our full EMCal acceptance.

The above is the basis of our statement that the proposed EMCal addition to ALICE allows jet measurements with sufficient acceptance, given the QCD rates, and with resolution close to the best possible given realistic estimates of the background, to study the fragmentation of quenched jets (item 1). Stated somewhat more strongly: The physics is in the fragmentation process and all that one can observe about it (longitudinal, transverse, flavor composition, etc.). The jet reconstruction is a means to this end which allows to find the jet and determine the primary parton energy. Beyond that, the reconstructed jet itself is of no particular interest. In this sense, detector hermeticity or a total acceptance grossly in excess of that needed to measure the fragmentation process in the range of interest with adequate statistics is irrelevant to heavy ion physics at the LHC.

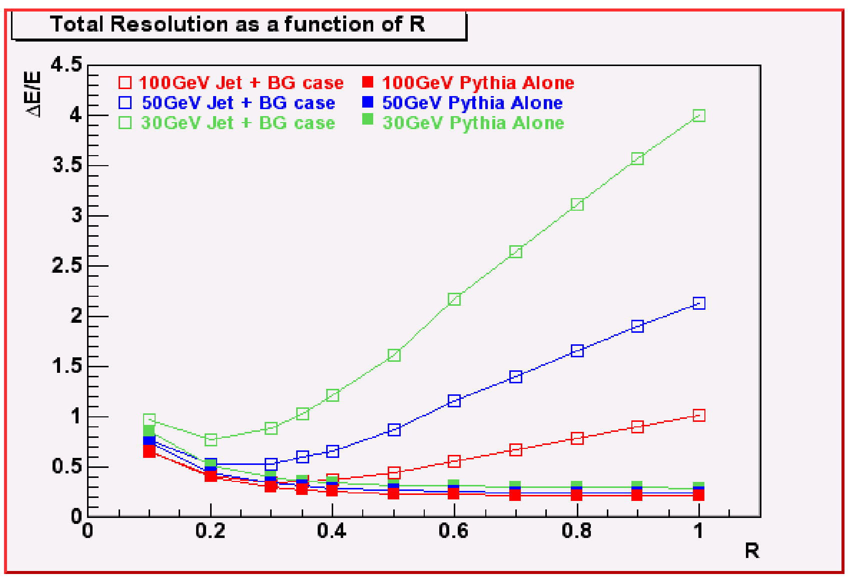
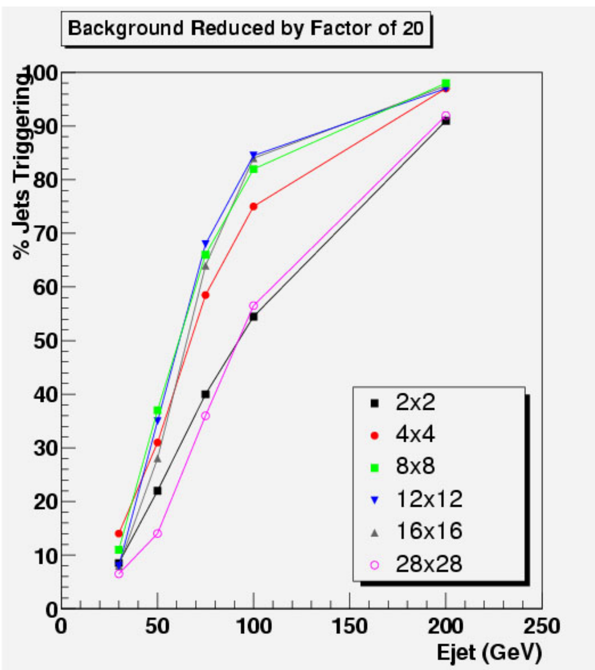


Figure 3. Energy resolution of reconstructed jets in central PbPb HIJING events for jets of 30,50, and 100 GeV/c, compared to PYTHIA alone.

[3] This bin size is comparable to the jet resolution.

A.III.2 Jet Triggers and Trigger Bias

Due to the fact that the ALICE TPC cannot be triggered at a rate which exceeds ~1kHz, it is important that a jet trigger be provided at Level 0 or Level 1 so that all rare, high P_T jet events are recorded. We have studied the performance of the high P_T photon trigger, planned for PHOS and the EMCal readout electronics, as a jet trigger. The trigger is formed from an energy threshold on the sums of overlapping tiles of calorimeter towers, similar to the PHENIX EMCal trigger. This type of trigger has already been demonstrated to be an effective γ and π^0 trigger in PHENIX and jet trigger in STAR. As shown in figure 4, the jet trigger efficiency reaches > 80% for 100 GeV/c jets for a background HIJING event rejection of a factor of 20. The P_T dependence of the resulting trigger bias is also illustrated in Fig. 4 for the charged hadron fragmentation function measured in the triggered jet cone. The P_T dependent part of the trigger bias is very small, <10%, for charged hadrons, as would be expected from the high trigger efficiency. We conclude that the EMCal can provide an effective unbiased trigger down to quite low jet energies (item 2 above). We note that for charged hadrons, a completely unbiased sample of charged hadrons is available from jets in minimum bias data allowing, by the usual methods, a correction for this <10% bias.



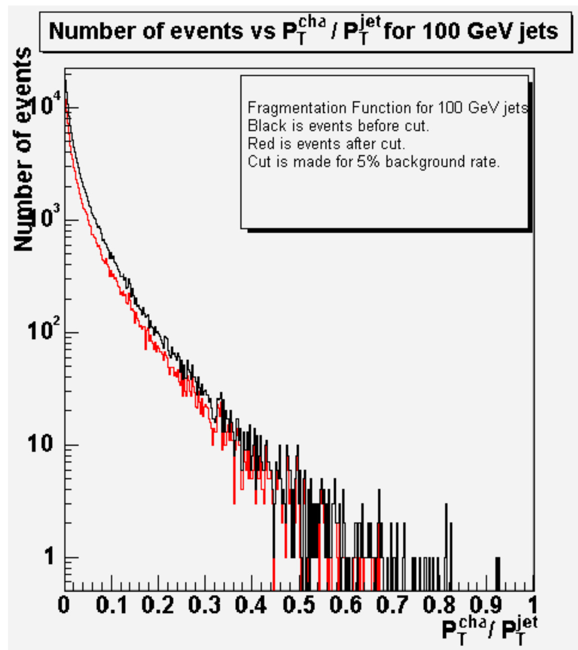


Figure 4. Left: The trigger efficiency as a function of the jet energy for EMCal trigger patches of various sizes in terms of the number of modules (2x2 towers). Right: The charged particle fragmentation function for 100 GeV/c jets which pass the EMCal trigger requirement (red) compared to the unbiased result (black).

A.III.3 A Model for the Jet Quenching Signal

We wish to gauge the expected physics performance of the Calorimeter/TPC combination compared to our current best available model for jet quenching at LHC energies. As discussed earlier, jet quenching cannot be observed calorimetrically as an energy loss because all but a tiny fraction of the energy lost by the primary parton remains in the jet cone. This conclusion follows from QCD calculations by Wiedeman *et al* of the pattern of radiated energy due to parton energy loss. Basically it is found that the medium induced gluon radiation produces a radiated energy pattern which is virtually indistinguishable from the vacuum gluon radiation that occurs as a normal component of parton fragmentation. It is essential, therefore to measure the redistribution of the energy in both the longitudinal and transverse directions that results from the parton energy loss process. In figure 5 we show a PYTHIA model of the longitudinal fragmentation function tailored to reproduce the radial distribution of radiated energy calculated by Wiedeman *et al*. We show the case of an unquenched 100 GeV parton and the superposition of 80+20 GeV partons and 80 +10+10 GeV partons. All three cases give the same total energy in the jet cone. The two quenched cases are seen to give identical fragmentation functions above Z ~0.1 but differ significantly in the low Z region where we have chosen only two simple cases. The trend at low Z is clear, radiation of more, lower energy partons produces a greater enhancement at low Z. The longitudinal and transverse fragmentation functions contain all that can be known about the parton energy loss and scattering. Thus, a precision, high efficiency, low ghost, tracking system is fundamental to jet quenching studies.

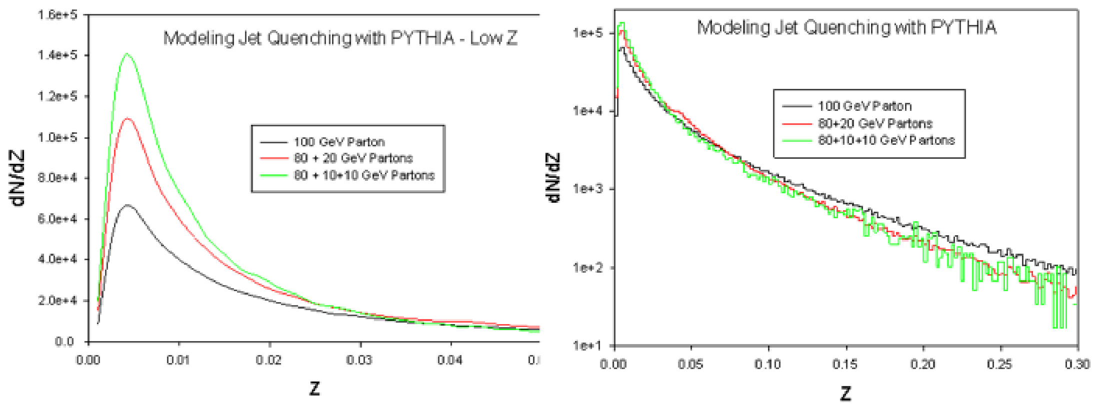


Figure 5. An event generator model for jet quenching patterned after the work of Wiedemann et al. Parton energy loss produces strong enhancement in the yield of soft particles in the jet cone that accompanies the suppression of high P_T particles. The degree of suppression at high P_T is probably significantly underestimated in this model.

A.III.4 Jet Reconstruction

Our studies are based on HIJING simulations of the underlying event into which PYTHIA jets of selected P_T are embedded. No jets are forced, i.e. triggered, in the HIJING backgrounds. However, because particle production in HIJING is based on the PYTHIA event generator, jets are present in our background calculations at the "zero bias" level (see e.g. fig.1). Because of cross section weighting, these background jets occur mainly at very low P_T. **These minijet and microjet backgrounds from the underlying PbPb event dominate the overall jet resolution for 50 GeV/c jets and contribute very significantly even at 100 GeV/c. This will be true of all jet measurements in the PbPb system at the LHC, independent of the apparatus used to make the measurement.** We emphasize that so-called parameterized background events, which are sometimes used to estimate detector performance issues in the LHC Heavy Ion environment, seriously underestimate background energy fluctuations[4] and should certainly not be used in connection with jet physics performance estimates.

The major part of our recent simulation effort has been devoted to understanding jet reconstruction efficiencies, backgrounds, and resolutions. Space restrictions prevent a full discussion of this important work but we briefly report the main results. First, as has already been mentioned, the fluctuations of the underlying event will dominate the jet resolution over most of the P_T range that is of interest for the study of medium effects with reconstructed jets, namely P_T = 30-150 GeV/c. At LHC energies, jet production cross sections are so large that they dominate even moderate P_T particle production. HIJING, which is based on the PYTHIA event generator and presumably accounts correctly for the rate of hard collisions predicts over 100 collisions per event with $P_T > 2$ GeV/c and one collision per event with $P_T > 20$ GeV/c. The cumulative effect of all these jets and mini-jets is a background with fluctuations that significantly impact jet finding and energy measurements. Indeed, only at the top end of the range of interest and above, will <u>detector characteristics</u> as opposed to <u>background considerations</u> significantly influence jet energy resolution.

Given the above, we have first extensively studied jet reconstruction in pp collisions. In addition to refining the basic method presented last year we have developed as an alternative method, a simple energy flow analysis based on the total energy carried into a jet cone by charged tracks, ΣE_{TPC}, and the total energy in the calorimeter ΣE_{EMCal} in that same cone. In this method the jet energy is

$$E_{jet} = A^*\Sigma E_{TPC} + B^*\Sigma E_{EMCal} - \Sigma E_{Bkg}$$

Where A and B are constants selected in a calibration procedure to reproduce the correct jet energy and best resolution. In this expression, ΣE_{Bkg} is the event-by-event background determined by sampling the underlying event outside the jet cone. In the case of pp collisions, ΣE_{Bkg} is negligible.

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[4] Such parameterized backgrounds contain only Poissonian fluctuations

The distribution of the reconstructed jet energy for PYTHIA jets of P_T=100 GeV/c using this method with a cone radius of R=0.3 (see above) is shown in figure 6. The RMS resolution is ~16%, which is comparable to the result obtained with the more elaborate method discussed in our pre-proposal.

The inclusion of the underlying HIJING event raises the RMS width for 100 GeV/c jets in central PbPb collisions to ~25%. If our intrinsic jet resolution were as low as 10%, this would only improve our resolution for these 100 GeV/c jets to ~22% in central PbPb events. This is the basis of our statement that the detector characteristics do no significantly effect jet performance in PbPb collisions.

In our method, the jet resolution achievable in pp is approximately independent of P_T. Consequently, our overall jet resolution degrades at lower P_T in PbPb collisions as the underlying event fluctuations gradually dominate the signal (see figure 4). This statement applies to all detectors measuring jets in heavy ion collisions at the LHC.

The various parameters that enter in our jet finding and jet reconstruction algorithms are not discussed due to space limitations.

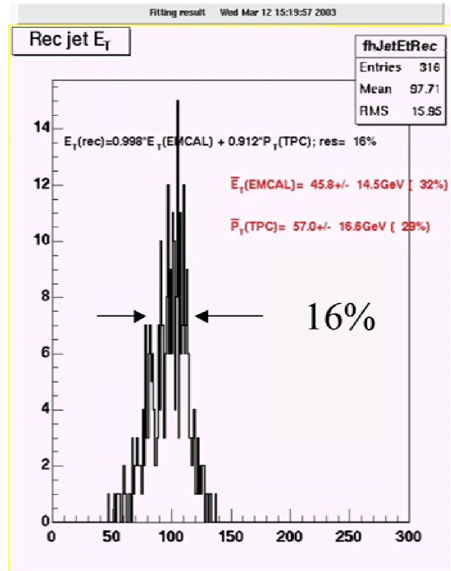

Figure 6. Reconstructed energy of 100 GeV/c jets.

A.III.5 Fragmentation

While jet quenching appears to leave a negligible signature in the integrated, calorimetric, energy flow, the momentum spectra of individual hadrons are strongly modified, as has already been shown at RHIC with inclusive single particle spectra. At LHC energies, jets contain many particles with momenta significantly greater than those of the underlying event so measurements sensitive to jet quenching can go well beyond the suppression of single leading particles as done up to now at RHIC. Clearly, the best signature of jet quenching at the LHC with reconstructed jets will be the longitudinal and transverse (with respect to the jet axis) distributions of individual hadrons.

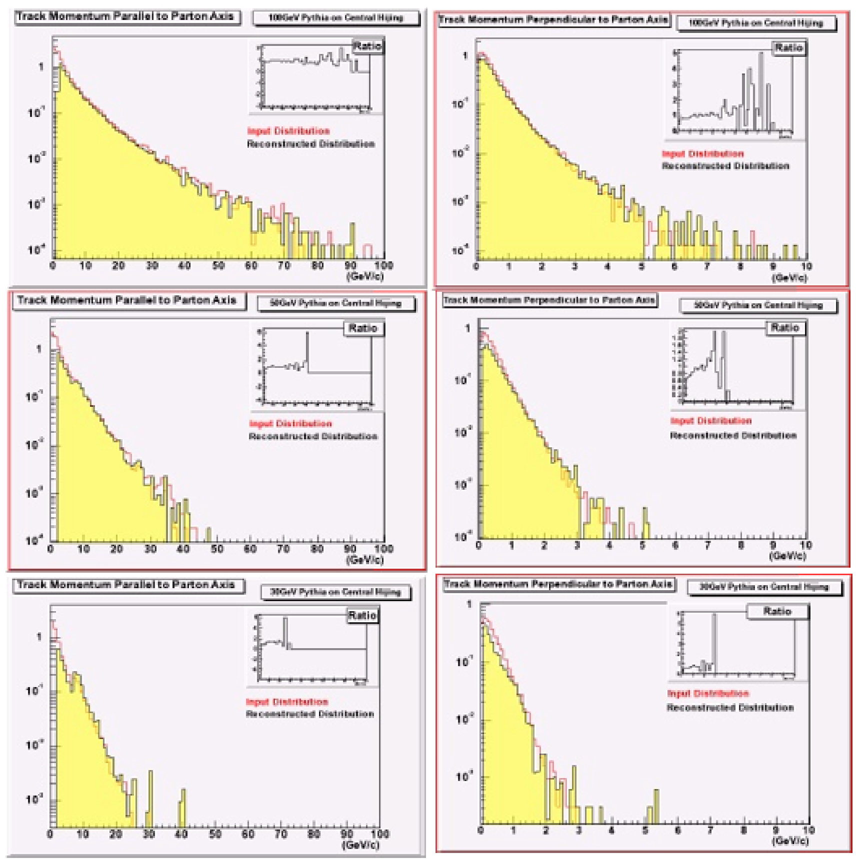

Figure 7. Reconstructed longitudinal (left) and transverse (right) momentum distributions of 30,50, and 100 GeV/c jets compared to input distributions (red). The statistics shown in figure vary from ~5% of an ALICE-year for the 100 GeV/c case to minutes of running for the 30 GeV/c jets

Figure 7 shows the background subtracted, longitudinal momentum, $P_{L,}$ left panels, and transverse momentum $j_{T,}$ (with respect to the jet axis) right panels, distributions of hadrons in jet cones of reconstructed 100, 50, and 30 GeV/c jet. Output distributions from the full simulation of the jet finding and reconstruction software are compared to the input distributions. Reproduction[5] of the input distributions is essentially perfect. . The accuracy of the reconstruction should be compared to the

[5] A slight discontinuity in efficiency at P ~ 7 GeV/c is visible in the 50 and, more so, 30 GeV/c P_L distributions. This is associated with the threshold seed for jet finding which is uncorrected in the present analysis. Also, the distributions are not

magnitude of the effect which might be expected, as indicated by the simulation studies of figure 5. From Vitev et al[6] we expect we expect much larger suppression factors than those resulting from our simple model. As a function of collision centrality their predict suppression factors vary from the factor of 2 range to the factor of >50 range depending on the primary parton $P_{T.}$

A.III.6 γ-Jet Tagging

Correlation measurements between γ's and high P_T particles or jets allows a very precise means to study the jet quenching phenomena in the case that the γ is produced directly in the lowest order q+g Compton process because the initial momentum of the recoiling quark is the same as that of the measured γ. The coincident measurement of the γ momentum can then be used to "calibrate" the energy of the reconstructed recoiling jet, or to provide directly the parton energy measurement needed for the jet quenching studies. In order to meaningfully perform the γ-tagging for the jet studies it is necessary to discriminate against the large background of photons from π^0 decay, which manifest themselves as isolated γ showers at lower P_T and as merged γ-like showers at high P_T. The merging showers can be identified by a cut on the shower shape. The γ vs π^0 rejection which can be obtained from shower shape for the proposed EMCal is shown in Figure 8 for momenta of 15, 25, and 50 GeV/c. It is seen that π^0 rejection factors of about an order of magnitude can be obtained up to 50 GeV/c with γ efficiencies of better than 50%. The corresponding upper rejection limit is about 100 GeV/c in the PHOS detector due to the smaller module size of (2.2cm) .

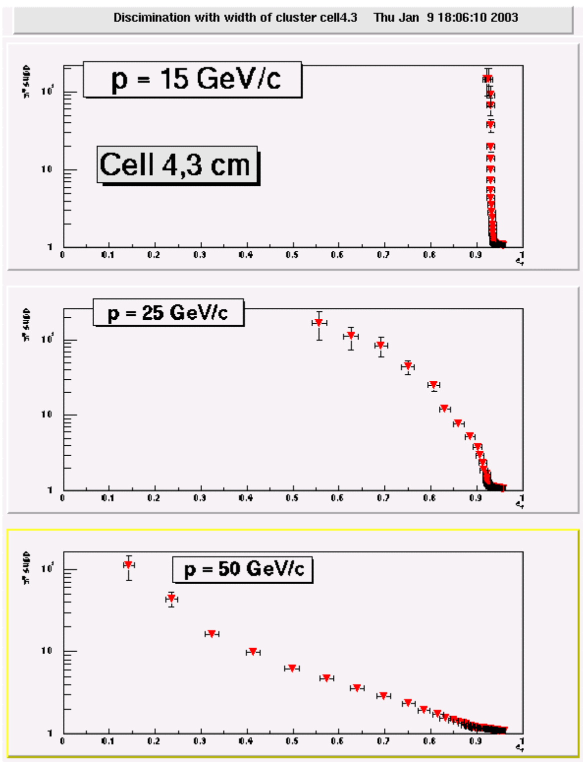

Figure 8. EMCal γ identification efficiency vs π^0 rejection factor varying the shower dispersion cut.

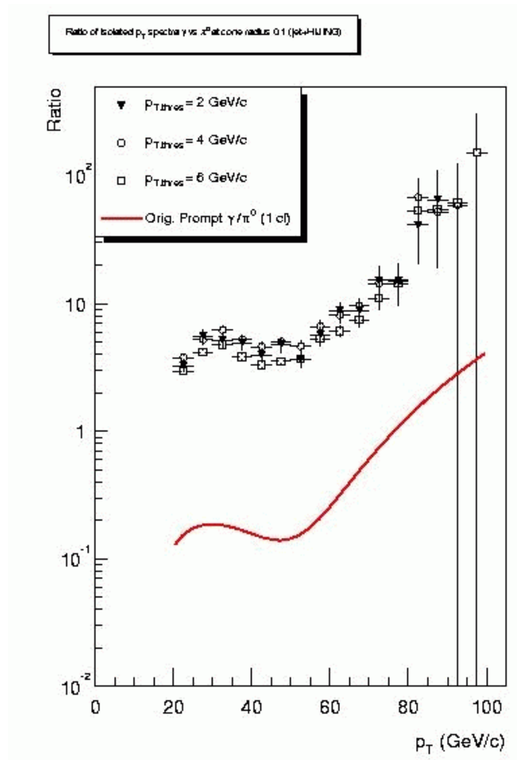

Figure 9. Ratio of direct γ to non-direct and γ-like clusters in PHOS after application of shower dispersion cut and isolation cuts with cone of R=0.1 (calculations are for $s^{1/2}$=14 TeV).

Figure 9 shows the ratio of direct γ's to background γ-like cluster's from merged γ's from π^0's in the PHOS detector before (curve) and after application of shower dispersion cut and cuts to remove clusters accompanied by tracks with various momenta thresholds within a rejection cone (isolation) around the cluster of R=0.1 (which provides a factor ~2 improvement

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corrected for the gradual rolloff of the TPC tracking efficiency which begins at about 500 MeV/c. These refinements will be added to future simulations.

[6]Vitev and Gyulassy, arXiv:hep-ph/0209161 v2 28 Oct 2002, M. Gyulassy, I. Vitev and X.N. Wang, Phys. Rev. Lett. **86**, 2537 (2001) [nuclth/0012092]; X.N. Wang, Phys. Rev. **C63**, 054902 (2001) [nucl-th/0009019

without significant signal loss). It is seen that the direct γ signal to background is significantly greater than 1 even to rather low momenta. The background rejection capabilities of the EMCal by shower shape will be similar up to about 50 GeV/c (item 4 of introduction). It is foreseen that jets fully reconstructed in the EMCal+TPC tagged by γ's measured in PHOS can be investigated to calibrate the jet reconstruction, *in situ*. These studies would then be extended to use γ's measured in the EMCal to study the fragmentation of the recoiling jets in that portion of ALICE without EMCal acceptance.

A.III.7 ALICE Jet Observables

For our purposes in ALICE, jets are reconstructed as one means to tag the primary parton energy and permit studies of the parton energy dependence of jet quenching phenomena. With reconstructed high P_T jets, a variety of jet features may be investigated in ALICE and many have been simulated in our on-going studies. A short list of these is summarized here:

(i) Modification of jet fragmentation functions, or the P_T distributions, within jet cones: The longitudinal and transverse momentum distributions of particles within the jet cone are modified by primary parton energy loss. In the longitudinal direction, we expect a reduction in the yield of high-P_T leading particles[7] and the enhancement in the yield of softer particles for both inclusive jets and tagged jets whose kinematics are constrained[8] by a hard photon or Z_0 in the opposite direction. In the transverse direction, interaction with the medium may result in significant "transverse heating".

(ii) Baryon – Anti-Baryon ratios at high P_T: Due to their higher color charge, hard gluons may lose up to approximately a factor 2 more energy than hard quarks while crossing the dense medium. Depending on the relative contribution of gluon fragmentation, this may modify the P_T dependence of the ratio of hadronic species, for example, the ratios $\overline{\Lambda}/\Lambda$ and $\overline{p}/p$

(iii) The medium-induced modification of strange and heavy quark fragmentation functions: Strange (s) and heavy quark (b,c) fragmentation functions as a special case of (i), above, provide the opportunity to study the mass dependence of the energy loss mechanism.

(iv) Baryon production mechanisms: Differential quenching of baryons and mesons is proving to be quite interesting at RHIC. The underlying mechanism(s) which result in significant deviations from pp jet-like meson/baryon ratios (e.g. K^o/Λ) are not unambiguously identified as yet but the ALICE-USA collaboration will study this physics in the distinctly different QGP environment produced at LHC energies over a very broad range of P_T, from the low end completely overlapping with RHIC results to a high end of >100 – 200 GeV/c.

(v) The dependence of hadronic fragmentation products on the nuclear geometry[5]: Due to the L^2 (or other) path dependence of energy loss on the in-medium path length, jet quenching phenomena are expected to show a strong and characteristic dependence on the impact parameter of the collision as well as to their orientation with respect to the reaction plane as determined, for example, from the elliptic flow pattern. At RHIC, it has been suggested that these expectations are reflected in the observed strong P_T dependence of elliptic flow v_2 for inclusive and identified hadrons. In ALICE, all aspects of the program outlined above in (i) through (iv) will be studied as a function of the reaction plane for reconstructed jets allowing a unique separation of the effects quenching variation with path length and parton P_T. As a specific example, consider "transverse heating" of the transverse fragmentation function. If this phenomena is observed in some P_T range at the LHC then it can be expected to show substantial dependence on the collision geometry. It is important to emphasize that collision geometry can only be established with a high granularity tracking system capable of tracking to low P_T with high efficiency and negligible ghosts. Studies at RHIC have shown that a considerable "non-flow" signal contaminates v_2 measurements based on lower order correlations such as the gross event shape. Higher order correlations such as the four particle cummulant have been shown to substantially reduce the non-flow contribution to v_2. These complications can be expected to be much more serious at LHC energy and we expect that event shapes determined from calorimetric or pixel data may be strongly biased by non-flow effects.

[7] X.N. Wang and M. Gyulassy, Phys. Rev. **D44**, 3501 (1991); M. Gyulassy and X.N. Wang, Nucl. Phys. **B420**, 583 (1994) [hep-ph/9306003]; X.N. Wang, M. Gyulassy and M. Plumer, Phys. Rev. **D51**, 3436 (1995) [hep-ph/9408344].

[8] X.N. Wang, Z. Huang and I. Sarcevic, Phys. Rev. Lett. **77**, 231 (1996); X.N. Wang and Z. Huang, Phys. Rev. **C55,** (1997).

B. Updated Costs and Schedules

The project time line has shifted by at least one full year from the optimum presented in last year's pre-proposal. This has had both cost and schedule consequences that we will outline in this section.

B.I Electronics

It was originally proposed that the ALICE-USA collaboration would play the leading role in the ALICE PHOS electronics design, prototyping, and final procurement. It was further proposed that these electronics would be suitable for the US EMCal, and thus the PHOS procurement would be essentially expanded with minor modifications to cover the EMCal needs. The base cost for this option, \$3.9M, was deemed to be well understood and the contingency was fixed at 25% (\$1M). Unfortunately, the schedule for this proposed approach to electronics acquisition was very tight, and with the shift of one year, it is no longer possible for the ALICE collaboration to rely on the ALICE-USA collaboration as a credible source of electronics for PHOS.

A new scenario now calls for the ALICE-USA collaboration to participate as consultants in the PHOS electronics development project which is to be carried forward by existing members of the ALICE collaboration. Staff members of LBNL and ORNL are actively participating in the role of consultants to insure that the PHOS electronics development will go forward in a manner that is still compatible with the needs of the US EMCal project. At the present time, a system design is going forward and we expect that the ALICE-USA collaboration will be in a position to participate in detailed costing soon, certainly prior to the submission of a full proposal. For guidance purposes, we include a high electronics cost estimate with a large contingency in the present document.

B.II EMCal

Three separate actions have increased the calorimeter cost relative to our former proposal. The first is a straightforward increase in the number of towers along with the removal of the preshower detector section. This change was motivated, as discussed above, by detailed simulation of π^o/γ discrimination in the PbPb environment which showed that finer tower granularity provided better discrimination than a preshower measurement. The cost increase here results mainly from the additional labor and optical fiber costs. The previous proposal contained no funding for preshower electronics so no savings could be realized by the removal of the preshower. The second cost increase resulted from a change in the detector integration plan that was necessitated by the one year shift in our schedule. Finally, in light of the second of these changes which creates some uncertainty in installation costs, we have increased the project contingency from an average of 19% to 25%. We have not considered trading scope to offset these cost increases but this could be an option. Note that although the calorimeter cost has increased, the overall project cost is essentially unchanged.

Table 1 shows our preferred funding profile, tempered by realistic annual funding levels and adjusted as described above. The totals shown here include in addition to TEC, R&D, pre-operating costs, ALICE Common fund contributions and contingency. FY03 and FY04 funding is indicated as pre-construction funding and construction funding is indicated to start in FY05.

In addition to the costs shown in table 1, Maintenance and Operating costs (M&O) will be assessed on an annual basis by CERN directly to each funding agency participating in any of the LHC experiments. The current scheme is to invoice an amount proportional to the 'number of scientists with PhD or equivalent'. The amount required for the present ALICE-USA collaboration could depend on the actual ALICE operating budget and is to be negotiated by the DOE with CERN in a manner consistent with practices already in place for US High Energy participation in LHC experiments.

Table 1. Proposed Project Funding Profile

WBS	Project	FY03	FY04	FY05	FY06	FY07	FY08	FY09	Total
		\$ 65	\$ 170	\$ 2,775	\$ 3,000	\$ 3,000	\$ 1,800	\$ 300	\$ 11,110
1.0	EMCal Construction Project			\$ 2,000	\$ 2,500	\$ 2,000	\$ 1,300	\$ 300	\$ 8,100
2.0	Electronics Project			\$ -	\$ 500	\$ 1,000	\$ 500	\$ -	\$ 2,000
3.0	ALICE Common Fund								
3.1	EMCal Infrastructure		\$ 30	\$ 575					\$ 605
3.2	Payment for Rails		\$ -	\$ 200					\$ 200
4.0	EMCal R&D	\$ 65	\$ 140	\$ -					\$ 205
		Pre Construction		Construction					

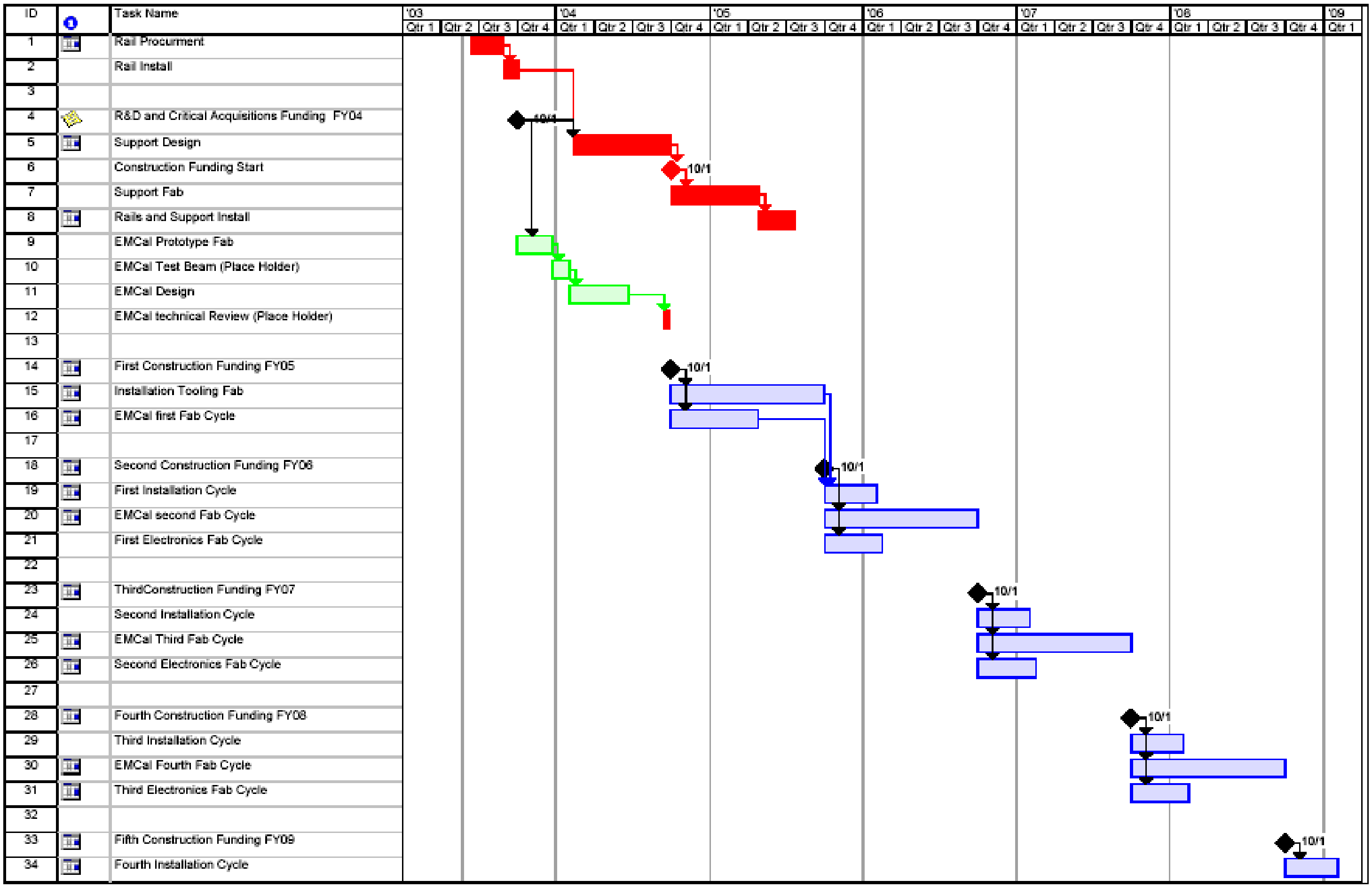

Table 2. Project Schedule.

C. R&D Work and Critical Project Timescales and Milestones

The high level project schedule is shown in table 2. The critical path activity is indicated in red and R&D activity in green. Given the funding profile shown in table 1, the critical path items include EMCal support rail design, fabricate, and install, and EMCal support structure design, fabricate, and install. These items must be completed on schedule to permit the later installation of the EMCal at any point in the future. Thus while it would be possible to stretch out or even delay the start of calorimeter production, the realities of the ALICE construction schedule will preclude even eventual installation of an electromagnetic calorimeter if these two items are not completed on schedule. The first of these critical path items is already in progress. ALICE management has supported the design costs of the EMCal rails and to stay on the schedule, they are now prepared to proceed with the procurement of these rails at a total cost of ~ \$200k within about two weeks, on June 15th. The ALICE management intends to proceed with this purchase of the rails unless the DOE advises them not to do so prior to June 15th.

In our former proposal, these rails were part of an in-kind contribution in lieu of a direct cash contribution to the ALICE common fund. As table 1 shows, we still indicate the support structure as an in-kind contribution but the cost of the rails is now indicated as a direct payment to the common fund.

The next critical path item is the support structure itself. This massive component must be installed inside the ALICE magnet in the middle of calendar 2005. After this date, the installation of the support structure will require virtually complete disassembly of the ALICE experiment and it is certainly not clear that either the ALICE or LHC schedule will permit this. To accomplish an on-time installation of the support structure, our schedule shows a design phase that goes on throughout early 2004 supported by \$30k in preconstruction funding to be followed by a procurement phase beginning with first construction funding in FY05. The minimum funding required in **early** FY05 to keep the project alive is \$575k.

D. Computing Needs

Already, several ALICE-USA institutions have become involved in the ALICE simulation effort. This effort is expected to grow significantly as ALICE prepares the software for physics analysis. ALICE is already in the process of its first mock data challenges. For this proposal, the computing resources from five different centers in the US and Europe have contributed simulations. This has been possible, in large part, due to the high degree of portability of the ALICE computing framework, AliRoot. This portability, along with continuing Grid developments, will allow and require that ALICE computing be distributed world-wide. Although the specific size and distribution scheme have yet to be decided, it is anticipated that at least one Tier-1/2 (regional center for simulations and data analysis with the permanent tape storage) and a number of Tier 3 facilities ("university level" computing farm serving collaboration with out, perhaps, permanent storage) will be located in the US. Significantly larger number of Tier4/5 (group clusters, desktops, laptops/PDAs) is anticipated. The NERSC/PDSF at the LBNL and the OSU at Ohio are possible hosts for Tier1/2. Equipment cost for Tier1/2 (calculated for PDSF) is estimated for $ 0.5 M in 2006-8, with recommended additions of 0.25 M/year in 2009 and 2010. Software infrastructure will require about 2 dedicated FTE's (grid development/integration, distributed production and user services). While one of these FTEs can be a skillful physics student or post doc from within the collaboration, the other one needs to be a computer professional. There will be also about 0.25 FTE required for management, participating in the meetings, etc. This person will be selected from the senior collaboration members. ALICE-USA is participating in the large ITR proposal entitled " Dynamic Workspaces Enabling Scientific Discovery" submitted to NSF in FY03 together with ATLAS and CMS to develop software for grid based data analysis. The proposal is under consideration.